

## Lecture Module - Sensors

ME3023 - Measurements in Mechanical Systems

Mechanical Engineering

Tennessee Technological University

## Lecture Module - Sensors

## Sensors

- Topic 1 - Introduction and Overview
- Topic 2 - IC and MEMS based Sensors

## Topic 1 - Introduction and Overview

- Analog and Digital Sensors
- Example 1: Distance or Range
- Example 2: Rotation

# Analog and Digital Sensors

a **sensor**, a physical element that employs some natural phenomenon... ..to sense the variable being measured

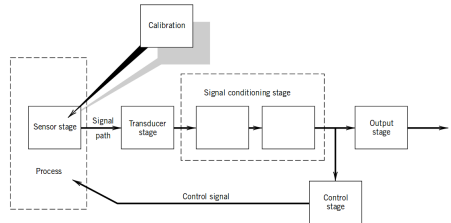
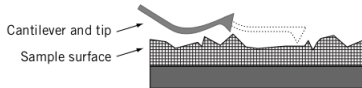


Figure 1.5 Components of a general measurement system.

# Analog and Digital Sensors

Sensors are typically classified as either **analog** or **digital** based on the type of signal that is output from the sensor.

However, this can be a misleading term. Many digital sensors operate based on analog circuit principles but require a digital circuit or MCU to operate or communicate.

Analog	Digital	Both?
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# Analog and Digital Sensors

## Other Classifications:

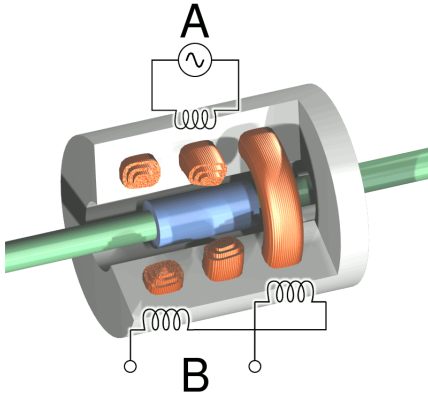
- Contact vs Non-Contact
- Programmable (Configurable) vs Non-Programmable
- By Measured Variable

## Example 1: Distance or Range

**Thought Exercise:** How do we measure **distance** (aka range)?

- What variable or quantity is used to describe **distance**?
  - 
  - 
  -
- What type of sensor is used to measure this?
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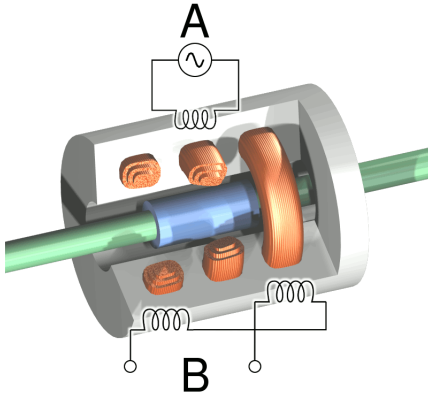
## Example 1: Distance or Range



LVDTs with NI  
LVDT Animation



## Example 1: Distance or Range



## Example 1: Distance or Range

- What applications require this type of sensor?
- 
- 
-

## Example 1: Distance or Range

- How does this type of sensor work?
- 
- 
-

## Example 2: Rotation

**Thought Exercise:** How do we measure rotation?

- What variable or quantity is used to describe rotation?
  - 
  - 
  -
- What type of sensor is used to measure this?
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## Example 2: Rotation

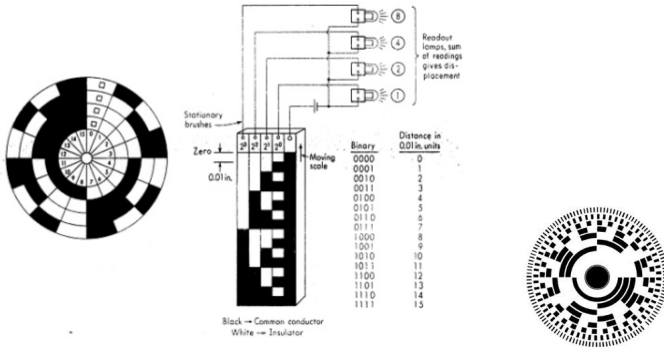
### Rotational Potentiometer



## Example 2: Rotation

### Absolute Encoder

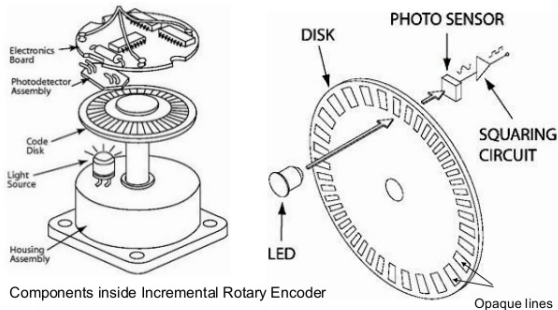
#### 4-Bit Binary Optical Absolute Encoder Disk



# Incremental Encoder

## 2. Types of Rotary Encoder - Incremental

### Construction of Incremental Rotary Encoder



Components inside Incremental Rotary Encoder

## Example 2: Rotation

- What applications require this type of sensor?
  - 
  - 
  -



## Example 2: Rotation

- How does this type of sensor work?
- 
- 
-

## Topic 2 - IC and MEMS based Sensors

- Integrated Circuits
- Micro Electro-Mechanical Devices
- Example 1: Accelerometer
- Example 2: Magnetometer and Digital Compass

# Integrated Circuits

An integrated circuit (also known as an IC, a chip, or a microchip) is a set of electronic circuits on one small flat piece[a] of semiconductor material, usually silicon. Large numbers of miniaturized transistors and other electronic components are integrated together on the chip.

# Integrated Circuits

## Activity: Group Brainstorming

List three applications or devices that use ICs and or IC based sensors.

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- 
-

•BAW filters  
•BAW duplexers  
•RF switch / variable capacitor  
•TCXO oscillators

•Accelerometer  
•Gyroscope  
•Electronic compass  
•Pressure sensor

MEMS micro-mirror

Microprojector

•CMOS Image Sensor  
•Auto-Focus actuator

•Front camera  
•ALS & Proximity sensor  
•Microdisplay

Silicon microphone

# Micro Electro-Mechanical Devices

MEMS (micro-electromechanical systems) is the technology of microscopic devices incorporating both electronic and moving parts. MEMS are made up of components between 1 and 100 micrometres in size (i.e., 0.001 to 0.1 mm), and MEMS devices generally range in size from 20 micrometres to a millimetre (i.e., 0.02 to 1.0 mm), although components arranged in arrays (e.g., digital micromirror devices) can be more than 1000 mm<sup>2</sup>. [1] They usually consist of a central unit that processes data (an integrated circuit chip such as microprocessor) and several components that interact with the surroundings (such as microsensors)

# Micro Electro-Mechanical Devices



**Activity:** Group Brainstorming List three sensors that are found on a high performance quadcopter or drone.

- 
- 
-

## Example 1: Accelerometer

An accelerometer is a tool that measures proper acceleration, which is the acceleration of a body in its own instantaneous frame.

Applications:

- Navigation Systems - Robotics - Aircraft - Missiles
- Personal Devices - Phones - Tablets
- Others:



## Example 1: Accelerometer

Thought Exercise: How do we measure acceleration?

**Activity:** Group Brainstorming

Explain one method for measuring acceleration of a body.

## Example 1: Accelerometer

Mechanical Accelerometers Consist of a damped mass spring system and a sensing device.

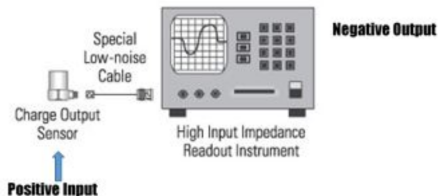
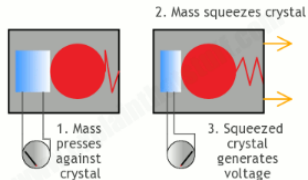
Types of accelerometers:

- Seismometer or Seismograph
- Piezoelectric - charge in material resulting from mechanical stress
- Piezoresistive - change in resistance resulting from mechanical stress
- Capacitive
- Multi Axis - triaxial

## Example 1: Accelerometer

### Piezoelectric accelerometer (charge mode)

Piezoelectric accelerometer www.explainthatstuff.com



## Example 1: Accelerometer

Piezoelectronic accelerometer with embedded amplifier circuit (ICP)

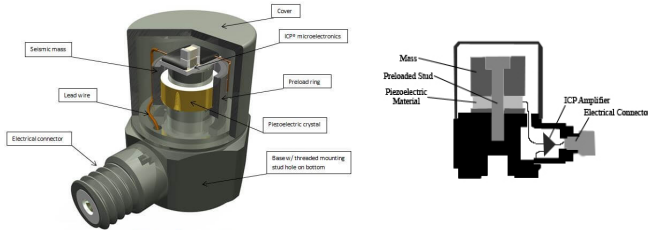
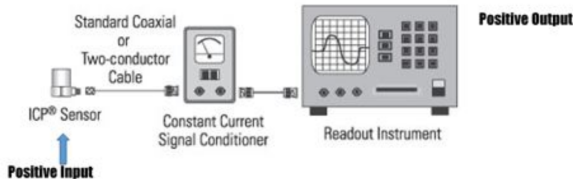


Figure 1: Typical ICP® Accelerometer



# Example 1: Accelerometer

## Capacitive accelerometer

Capacitive accelerometer

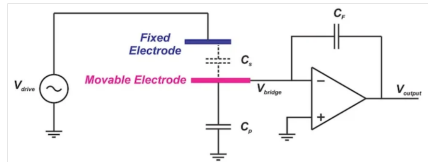
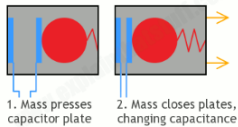


Figure 5

$$V_{output} = -\frac{C_s}{C_F} V_{drive}$$

$$C = \epsilon \frac{A}{d}$$

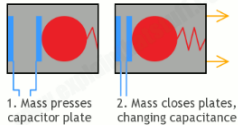
$$V_{output} = -\frac{d_F}{d_s} V_{drive}$$

$$V_{output} = \frac{d_F}{d_0 + \Delta d} V_{drive}$$

# Example 1: Accelerometer

## Capacitive accelerometer

Capacitive accelerometer



www.explainthatstuff.com

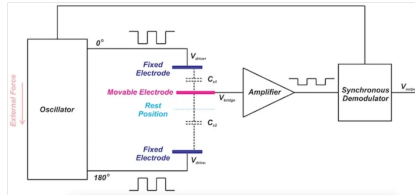


Figure 4. Image (adapted) courtesy of Analog Devices

$$V_{bridge} = \frac{C_{s1} V_{drive+} + C_{s2} V_{drive-}}{C_{s1} + C_{s2}}$$

$$d_{s2} = d_0 + \Delta d$$

$$V_{bridge} = \frac{d_{s2} V_{drive+} + d_{s1} V_{drive-}}{d_{s1} + d_{s2}}$$

$$V_{drive+} = -V_{drive-}$$

$$d_{s1} = d_0 - \Delta d$$

$$V_{bridge} = \frac{\Delta d}{d_0} V_{drive+}$$

capacitive accelerometer wiring Position and motion sensors

## Example 2: Magnetometer and Digital Compass

**Thought Exercise:** How do we measure **orientation**?

- What variable or quantity is used to describe motion?
  - 
  - 
  -
- What type of sensor is used to measure this?
  - 
  - 
  -

## Example 2: Magnetometer and Digital Compass

- What applications require this type of sensor?
- 
- 
-



## Example 2: Magnetometer and Digital Compass

A magnetometer is a device that measures magnetic field or magnetic dipole moment. Different types of magnetometers measure the direction, strength, or relative change of a magnetic field at a particular location. A compass is one such device, one that measures the direction of an ambient magnetic field, in this case, the Earth's magnetic field. Other magnetometers measure the magnetic dipole moment of a magnetic material such as a ferromagnet, for example by recording the effect of this magnetic dipole on the induced current in a coil.